WIND TUNNEL WORK AT THE N.P.L.

Abstract of Paper read by Mr. W. L. Cowley, A.R.C S., D.I.C., Wh.Sch., Member, at a meeting of the Institution held at the Engineers' Club, W.1. on January 26th, 1923. Mr. H. B. Molesworth in the Chair.

MR. COWLEY said :—

The science of aeronautics owes much for its development to the work of the wind tunnel. Here experiments of a simple nature and manageable dimensions can be carried out upon models of various types of machines or parts, under standard and ideal conditions. The results of the tests, after due allowance has been made for the size of the model, the wind speed, etc., may be used directly for design data, but probably even greater value may be attached to the wind tunnel work for the reason that we are enabled to study thereby complicated aerodynamical problems which in themselves are too difficult for direct solution, by leading up to them step by step through a series of simpler experiments. In this way the theory and technique of the subject may be developed, and even if complete solutions are not always forthcoming, the work becomes exceedingly valuable to the designer.

THE WIND TUNNELS.

The tunnels in use in the Aerodynamics Department at the National Physical Laboratory are : two four feet square in cross section, three seven feet square, and one called the duplex of section, seven feet by fourteen feet. The general appearance of the channels may be judged from the lantern slides.

The wind tunnels are of length approximately 26 ft., 45 ft., and 78 ft. for the 4 ft., 7 ft. square and the duplex respectively, and are built fairly symmetrically in a room which acts as a return flow chamber. The air is drawn through the tunnel by means of an airscrew and passed into the room again through a distributor which is constructed of laths spaced so as to give a fairly even flow. The working portion of the tunnel is about half way along its length where the flow is steady and uniform to a high degree of accuracy. The model to be tested is suspended in this region and the component forces and moments

https://doi.org/10.1017/S2976690700000231 Published online by Cambridge University Press

measured upon balances situated outside the channel but connected to the model by levers or wires.

In the following table are given the main dimensions of the tunnels :—

Section.	Length.	Length of cone in front of fan.	Length of distributor.	Height of centre line.	Size of Room Length	Width.	Height.	Motor.	Max. air speed per second.
	ft.	ft.	ft.	ft.in.	ft.	ft.	ft.	h.p.	
4 ft. square (No. 1 & No. 2)	26	6	22	8 6	60	22	18	20	80
7 ft. square (No. 1)... ...	45	14	30	17	100	40	35	60	60
7 ft. square (No. 2)... ...	45	14	30	18	100	40	35	200	80
7 ft. square (No. 3)... ...	50	14	36	18	110	40	35	200	90
7 ft. × 14 ft. (Duplex) ...	78	24	30	21	150	70	40	Two 200	110

The voltage of the electrical system is 400 direct current. The duplex has a honeycomb partition across the building 54 feet from the distributor end. Two airscrews are used in this tunnel to drive the air and are arranged side by side so that the main stream after leaving the tunnel proper divides into two, one part through each airscrew, and again unites in the distributor. An interesting electrical device is used to maintain equal speeds in the two motors. In each armature three tappings are taken at points differing in Phase by 120°, and these are connected to slip rings. The machines are then joined together by connecting corresponding rings through resistances. If one machine runs at a slightly lower speed than the other so that the two cease to be in phase the faster becomes a three-phase dynamo in effect by supplying three-phase current to the slower, which in its turn becomes a motor, although at the commutator ends both are direct current machines. In this way a tendency always exists to mantain equal speeds in the two motors.

THE BALANCES.

The first type of balance to be used in the wind tunnels was that known as the lower balance, situated underneath the tunnel, the model being mounted on a spindle attached to the balance. On this balance in its original form four measurements can be effected, viz., a vertical force and three moments, one about a vertical axis and two about horizontal axes. The latter measurements are done by mounting the oscillatory part of the balance on a hardened steel point resting in a hardened steel cup. Two horizontal balance arms at right angles to each other are fixed rigidly to this portion so that the axes of the arms intersect at the main suspension point. The balance is constrained from rotating about a vertical axis through the suspension point by means of a strut and "C" spring connected to a third arm, a backward extension, in effect, of one of the balance arms. The strut is placed horizontally between this third arm and a piece rigidly connected to the fixed standard and the "C" spring

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is slipped over to make the balance arm sit firmly on the strut. In this way the balance is only free to rotate about two horizontal axes at right angles, viz., the two balance arms. By means of scale pans, weights and riders, both beams may be balanced simultaneously and the two moments measured.

One arm only may be used if required by supporting the other on a strut so as to prevent its motion.

To determine the moment about the vertical axis the strut and " C " spring are removed and the balance constrained to rotate about a vertical axis by allowing a cup, pressed by a spring, to engage a point which is fixed in the balance about three feet below the main suspension point. A bell crank lever with one limb connected to the extension arm of the balance by means of a strut and " C " spring and the other carrying a scale pan and rider, enables the moment about this axis to be measured.

The vertical force is measured on a parallel motion. Two beams of the same dimensions are supported on knife edges and engage the balance one at the lower point the other at a point just above the main supporting point. The lower beam is loaded at the end by a weight sufficiently large to take the major portion of the weight of the balance and the other beam holds the scale pan and rider. In this way the balance as well as the vertical force on the model is weighed, but the former appears in the zero reading of the balance and therefore does not affect the measurements.

The experimental work mainly carried out on this balance is upon bodies that give symmetrical force systems. An aerofoil for example or a complete machine unyawed relative to the wind will experience an aerodynamic force lying in the plane of symmetry. If, therefore, the aerofoil or machine be mounted on the balance so that the span is vertical the lift and drag will have a leverage about the two horizontal beams, which have been arranged to be parallel to these forces, equal to the distance between the plane of symmetry and the main supporting point. These beams, when allowance is made for this leverage, may be regarded as measuring the lift and the drag. The moment about the vertical axis is a measure of the pitching moment. The angle of incidence of the model may be varied by rotating the balance head into which the spindle supporting the model is fixed.

Besides aerofoils and complete machines, aeroplane bodies, seaplane floats, etc., may be tested for lift drag and pitching moment and by mounting the model horizontally, i.e., in the flying attitude and varying the yaw, the yawing moment about the c.g. can be measured. The vertical force measurement may be utilised to determine (a) the lift in the latter method of support and (b) the lateral force in the former.

The force on the model is completely determined when the three components of force along three axes, taken perpendicular to each other, and the three component moments are known. By using the two methods of suspension above we may determine these six quantities. These are if axes are chosen parallel and perpendicular to the wind, the lift, drag and cross wind forces and the pitching, yawing and rolling moments.

The objection to tests of this nature for models of complete machines is the difficulty of mounting the model on its side. In fact it has been found desirable in many cases to measure the three forces and three moments for one setting only, viz., horizontal. This necessitates the introduction of a fresh device.

In all six quantities have to be determined, but, with the horizontal method of suspension and the balance in the form already given, four only can be taken. Two other readings are therefore necessary before the work is complete. To do this the model and the spindle of the balance are connected together by what are in effect a set of gimbal rings. Thus at the top of the spindle a horizontal ring is connected so that it can oscillate on the spindle about a horizontal axis perpendicular to the wind. Another ring is placed concentric round this and connected so that it can oscillate about that ring with respect to an axis parallel to the wind. The model is fixed to this outer ring. Four wires, two fore and aft and two on either side of the model, are connected to two extra rocking arms fitted in the balance below so that the moments about these two axes in the rings may be measured. If the centre of the rings is placed vertically over the main suspension point one of these readings gives the pitching moment and the other the rolling moment with respect to the axes of the gimbal set. The yawing moment and the lift or vertical force can be measured on the lower balance and the moment of the drag plus the pitching moment and the moment of the cross wind force plus the rolling moment measured on the two horizontal balance arms. In this way all six quantities may be determined for one setting of the model.

The method of measuring forces just given, although very simple and convenient, has one serious defect in certain classes of problems. The spindle that is used to attach the model to the balance greatly interferes with the flow when the model is of very fine "streamline" form. The most satisfactory suspension found for such cases is by means of fine wires. The weight of the model is taken mainly by two vertical wires and a small spindle or sting as it is called is led out from the rear of the model to a balance which measures the drag on the body. In cases where the vertical component is also required, such as in aerofoil tests for example, the force in the plane of the two supporting wires is measured on a balance resting on the roof of the tunnel, and the vertical component of the force at the sting hinge is measured on another balance. The balances for measuring this latter force and also the drag are usually placed on the roof of the tunnel, although the lower balance may be used. The latter however does not give such accuracy and ease of working as the former.

In the Duplex wind tunnel the balance holding the supporting wires is so constructed that it may be used to measure either the sum of the vertical component of the tension in the wires, or the difference. The latter arrangement may be used for measuring rolling moments.

The balances mentioned above are the products of skilful design and accurate workmanship. The lower balances for example are easily capable of measuring forces up to 10 lbs. and in order to obtain the requisite stiffness the weight of the movable portion of the balance in some cases exceeds 60 lbs. All this

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weight is taken on a single hardened point when the horizontal balance arms are used, but yet not only may a force of 10 lbs. be accurately measured but also a force as low as 1/10,000th of a pound may readily be detected.

THE PROGRAMME OF WORK.

The work of the Aerodynamics Department is fairly extensive and only a short résumé can be given. As this work is confidential before publication by the Air Ministry, an account will only be given here of those experiments that have been mentioned in the reports of the N.P.L.

In the main the object of the work of this department is to supply accurate data to the designer and to establish and build up theories which may be used as a basis for design.

(a) Aerofoil Work.—The aerofoil supplies a fairly large amount of work: For design data an exhaustive series of experiments are now being carried through upon aerofoils of R.A.F. 15 section, chord 6 ins. and span 36 ins., to determine monoplane and biplane characteristics. The monoplane was tested over a speed range 20 f/s to 90 f/s with square and rounded wing tips. The square-ended aerofoil has been tested in all tunnels except the duplex and is now being tested at various foreign laboratories for the purpose of comparing the various channels. An airship model is also being tested in these international trials.

The R.A.F. 15 biplane experiments are being carried out with square wing tips for staggers—15°, 0°, 15° and 30°, and gap/chord ratios at each stagger of 0.5, 0.75, 1.0 and 1.5 over in angle range—6° to 40°. The high angles are of interest for stalled flight and stability questions. The forces on the separate planes are also being measured as well as on the combination.

(b) Prandtl's Aerofoil Theory.—An aerofoil theory proposed by Prandtl has shown much promise and is being investigated at the N.P.L. An important development is the application to tapered wings such as internally-braced monoplane wings. Prandtl's theory enables us to calculate the performance of a wing whose section varies in shape and dimensions along the span if the characteristics of a series of uniform aerofoils whose sections correspond with various sections along the wing are known. The agreement between calculation and experiment is remarkably good.

(c) Control Above the Stall.—Other work on aerofoils included in the N.P.L. programme is pressure plotting over various forms of wing tips and the testing of various wing modifications, the applications to aileron controls being specially considered.

The chief work carried out in the latter case is the measurement of rolling and yawing moments produced by various types of aileron controls or their equivalent, for angles of incidence of the wings greater than the stall, as well as over the normal flying range.

A number of machines have been tested on the three forces and three moments balance at angles of incidence approaching 40°, in order to supply data for this branch of the work and for controllability.

(d) Spin and Stability.—Interlaced with the problem of control at high angles is the interesting stability question of spin or autorotation. The effect of stagger and decalage upon autorotation has been investigated and other work is on hand. A considerable amount of work has already been carried out and much remains to be done on experiments of an ideal and simple nature in order to develop the theory of this subject and technique of the more complicated experiments.

Investigations have been carried through, and further work still remains in the programme on the measurement of the stability derivations Mq, Lp and Nr and also the complex derivatives Lr and Np.

(e) Airscrew Work.—The airscrew programme is very extensive and includes :—

(1) Pressure plotting over the airscrew blade.
(2) Testing of a family of airscrews.
(3) Effect of slip stream upon bodies, etc., and the interference of the fuselage upon the airscrew.
(4) Pressure head in the slip stream.

(f) The Whirling Arm.—Originally propellers were tested on the whirling arm but more satisfactory results and a wider range are obtained by testing in the wind tunnels. As a consequence of this the whirling arm could only claim to be of use for Pitot tube calibrations, but it is now becoming increasingly evident that its utility may be extended. Many stability questions for example can be most satisfactorily solved on the whirling arm, such as the effect of higher angular velocities upon the stability derivatives. Another question that requires investigating is the effect of the propinquity of the ground or sea upon aircraft. In the wind tunnels two methods are used to represent the ground. One is to place a board in the tunnel parallel to the wind direction and the other is to make a reflected image of the model with respect to the ground surface so that the average flow in the near vicinity of that surface is along the ground plane. Neither of these two methods are rigidly correct, and unfortunately give results of sufficient divergence to shake confidence in either method. The check can best be applied on the whirling arm where the actual conditions can be almost completely reproduced.

(g) Scale Effect and High-Pressure Tunnel.—Probably one of the most important questions in model work is that of scale effect, that is the relation between the results obtained for experiments upon a model at a certain speed with those obtained for a geometrically similar model, or the full-scale machine at another scale and speed. The dynamical similarity law is under investigation, comparison is being made between the wind tunnel results for a certain model with those from experiments carried out in the Froude Tank.

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Further work upon this question may be forthcoming from experiments in a high-pressure tunnel. The force coefficients by the similarity law depend upon the ratio of the kinematic coefficient of viscosity to the product of speed times the linear dimensions. Now if we work out at the same value of this ratio for the model as we do for full scale the force coefficients will be the same. Usually the product speed times length is much smaller for the model than for the full scale and, since the same fluid is used in both cases so that the coefficient of viscosity will be the same, a direct comparison cannot be made. By using compressed air and a consequent increased coefficient of viscosity the effect of a change in the produce speed times length may be counterbalanced by the effect of change in that coefficient.

A wind tunnel 4 ft. square working in a compressed air chamber (10 atmospheres pressure) has already been constructed in America. There are very good reasons to believe, however, that the high-pressure tunnel is a most satisfactory method of studying the complex question of "Scale Effect" and considerable development might be expected in this direction in future.

DISCUSSION.

MAJOR GNOSSPELIUS.—I have listened to the lecturer with great interest, and fully agree with him as to the value of model work, for that is the only way to find anything out at a reasonable cost.

I am rather doubtful, however, as to whether you get a steady flow in the wind tunnels. It is uniform, I know, but is it also steady? I think that if one could check the wind tunnel results with those obtained by experiment in still air there would be quite a difference, and I do feel that this question of steady flow or otherwise is the weak point of the tunnels. It seems to me that it might account for some of the extraordinary effects which have been found by the N.P.L.

High-lift wings always suffer from this difficulty. I am not sure whether the top life curve which you get in a tunnel is not affected by the turbulence of the air.

I do not know whether you have studied holes in lift curves. It seems to me that if you could explain those holes it would go far to getting theories on rather a better basis. If we could only understand the differences in flow we should get much better success. I hope the N.P.L. will be able to solve this problem.

I thank Mr. Cowley very much for his interesting paper.

CAPTAIN SAYERS.—I thank Mr. Cowley very much for his interesting description of the apparatus and the type of work which has been done at the N.P.L. I

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